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FORM PTO-1390 (REV. 9-2001) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEY 'S DOCKET NUMBER EEC-TWUL-P2 U.S. APPLICATION NO. (If known, see 37 CFR 1.5 10/019180
INTERNATIONAL APPLICATION NO. PCT/GB00/02434	INTERNATIONAL FILING DATE June 22, 2000	PRIORITY DATE CLAIMED June 22, 1999

TITLE OF INVENTION
Correlation Analysis in the Phase Domain

APPLICANT(S) FOR DO/EO/US
Ian D. Kimber and Robert Alcock

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. [X] The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is attached hereto (required only if not communicated by the International Bureau).
   b. [ ] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [ ] is attached hereto.
   b. [ ] has been previously submitted under 35 U.S.C. 154(d)(4).
7. [X] Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). [unexecuted]
10. [ ] An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
14. [ ] A SECOND or SUBSEQUENT preliminary amendment.
15. [ ] A substitute specification.
16. [ ] A change of power of attorney and/or address letter.
17. [ ] A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. [ ] A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. [ ] A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. [X] Other items or information:

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U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 10/019180 NEW APPLICATION	INTERNATIONAL APPLICATION NO. PCT/GB00/02434	ATTORNEY'S DOCKET NUMBER EEC-TWUL-P2

	CALCULATIONS	PTO USE ONLY
21. ☒ The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .... **$1040.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO .... **$890.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... **$740.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$710.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	$	
Total claims	24 - 20 =	4	x **$18.00**	$ 72	
Independent claims	4 - 3 =	1	x **$84.00**	$ 84	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$280.00**	$	
TOTAL OF ABOVE CALCULATIONS =				$ 1046	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. +				$	
SUBTOTAL =				$ 1046	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$	
TOTAL FEES ENCLOSED =				$ 1046	
				Amount to be refunded:	$
				charged:	$

a. ☒ A check in the amount of $ 1046 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ________ in the amount of $ ________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 15-0699. A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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REGISTRATION NUMBER

ATTY. DOCKET NO.: EEC-TWUL-P2

EXPRESS MAIL CERTIFICATE
EXPRESS MAIL MAILING LABEL NO. EL 793494058 US
DATE OF DEPOSIT: December 21, 2001

The undersigned hereby certifies that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Commissioner of Patents and Trademarks, Washington D.C. 20231.

December 21, 2001
DATE

Joshua S. Broitman
Reg. No. 38,006

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

Ian D. Kimber et al. : Group Art Unit: Unassigned

Serial No.: NEW APPLICATION : Examiner: Unassigned

International Application Number: PCT/GB00/02434

International Filing Date : June 22, 2000

Earliest Priority Date : June 22, 1999

Title: CORRELATION ANALYSIS
IN THE PHASE DOMAIN

Box PATENT APPLICATION
Assistant Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Sir:

Prior to computation of the filing fee in the national stage of the above-referenced international application, please enter the following amendments:

IN THE CLAIMS:

Please amend claims 3, 4, 6, 8, 9, 10, 12, 15-16, 18,20-22, and 24, as follows.

CLAIMS:

3. (Amended) A method according to claim 1 [or 2], wherein the signals are audio signals.

4. (Amended) A method according to [any preceding] claim 1, wherein the at least one filter includes a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence.

6. (Amended) A method according to [any preceding] claim 1, wherein the at least one filter includes a second filter for identifying regions in the frequency spectrum of a cross correlation function likely to exhibit a correlated phase between adjacent frequencies in its Fourier Transform.

8. (Amended) A method according to claim 6 [or 7], [including] further comprising calculating the time delay between the common signal in the input signals by tracking the phase difference between the input signals as a function of frequency using the second filter.

9. (Amended) A method according to claim 6 [to 8], [including] further comprising calculating variations in the time delay between the common signal in the input signals as a function of frequency using the second filter.

10. (Amended) A method according to [any preceding] claim 6, [including] further comprising using a third filter to remove frequencies which do not have sufficient amplitude.

12. (Amended) A method according to [any preceding] claim 1, wherein the at least one filter includes a fourth

filter for compensating the input signals for dispersion effects.

15. (Amended) An apparatus [Apparatus] according to claim 13 [or 14], wherein the signals are audio signals.

16. (Amended) An apparatus [Apparatus] according to [any of claims] claim 13 [to 15], wherein the at least one filter includes a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence.

18. (Amended) An apparatus according to [any of claims] claim 13 [to 17], wherein the at least one filter includes a second filter for identifying regions in the frequency spectrum of a cross correlation function likely to exhibit a correlated phase between adjacent frequencies in its Fourier Transform.

20. (Amended) An apparatus according to claim 18 [or 19], including calculating the time delay between the common signal in the input signals by tracking the phase difference between the input signals as a function of frequency using the second filter.

21. (Amended) An apparatus according to [any of claims] claim 18 [to 20], including calculating variations in the time delay between the common signal in the input signals as a function of frequency using the second filter.

22. (Amended) An apparatus according to [any of claims] claim 13 [to 21], including a third filter to remove

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frequencies which do not have sufficient amplitude.

24. (Amended) An apparatus according to [any of claims] claim 13 [to 23], wherein the at least one filter includes a fourth filter for compensating the input signals for dispersion effects.

REMARKS

This Preliminary Amendment is filed together with a Transmittal Letter to the United States Designated Office (DO/US) Concerning a Filing under 35 U.S.C. § 371 (entry into the U.S. national stage). The above-identified amendments are made to eliminate multiple dependent claims and to limit U.S. national filing fees and to improve form. No new matter has been introduced.

A clean copy of the claims is attached, as an addendum, hereto.

Respectfully submitted,

12/21/2001
Date

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Atty. Docket: EEC-TWUL-P2

ADDENDUM

SUBMISSION OF CLEAN CLAIMS PURSUANT TO 37 CFR § 1.121

In compliance with 37 CFR § 1.121, the Applicants hereby submit a "clean" copy of the claims now pending in this application as follows:

1. A method for detecting and locating a common signal within two input signals using correlation based techniques, comprising providing at least one filter by analyzing the phase of the input signals in the frequency domain; filtering the input signals in the frequency domain using said at least one filter; and performing cross correlation of the filtered signals.

2. A method for detecting and locating leaks in a fluid carrying pipe using correlation based techniques, comprising: detecting two input signals from the fluid carrying pipe; analyzing the phase of the input signals in the frequency domain to provide at least one filter; filtering the input signals in the frequency domain using the at least one filter; and performing cross correlation of the filtered signals.

3. A method according to claim 1, wherein the signals are audio signals.

4. A method according to claim 1, wherein the at least one filter includes a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence.

5. A method according to claim 4, wherein the first

filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of the plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

6. A method according to claim 1, wherein the at least one filter includes a second filter for identifying regions in the frequency spectrum of a cross correlation function likely to exhibit a correlated phase between adjacent frequencies in its Fourier Transform.

7. A method according to claim 6, wherein the second filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of the plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

8. A method according to claim 6, further comprising calculating the time delay between the common signal in the input signals by tracking the phase difference between the input signals as a function of frequency using the second filter.

9. A method according to claim 6, further comprising

calculating variations in the time delay between the common signal in the input signals as a function of frequency using the second filter.

10. A method according to claim 6, further comprising using a third filter to remove frequencies which do not have sufficient amplitude.

11. A method according to claim 10, wherein the third filter is constructed using a method comprising: applying a digital threshold to the product of the spectra of the two input signals.

12. A method according to claim 1, wherein the at least one filter includes a fourth filter for compensating the input signals for dispersion effects.

13. Apparatus for detecting and locating a common signal within two input signals using correlation based techniques, comprising a computer including: means for providing at least one filter by analyzing the phase of the input signals I the frequency domain; means for filtering the input signals in the frequency domain using said at least one filter; and means for performing cross correlation of the filtered signals.

14. Apparatus for detecting and locating leaks in a fluid carrying pipe using correlation based techniques, comprising: detectors for detecting two input signals from the fluid carrying pipe; a computer including means for analyzing the phase of the input signals in the frequency domain to

provide at least one filter; means for filtering the input signals in the frequency domain using the at least one filter; and means for performing cross correlation of the filtered signals.

15. Apparatus according to claim 13, wherein the signals are audio signals.

16. Apparatus according to claim 13, wherein the at least one filter includes a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence.

17. An apparatus according to claim 16, wherein the first filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

18. An apparatus according to claim 13, wherein the at least one filter includes a second filter for identifying regions in the frequency spectrum of a cross correlation function likely to exhibit a correlated phase between adjacent frequencies in its Fourier Transform.

19. An apparatus according to claim 18, wherein the second filter is constructed using a method comprising:

selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

20. An apparatus according to claim 18, including calculating the time delay between the common signal in the input signals by tracking the phase difference between the input signals as a function of frequency using the second filter.

21. An apparatus according to claim 18, including calculating variations in the time delay between the common signal in the input signals as a function of frequency using the second filter.

22. An apparatus according to claim 13, including a third filter to remove frequencies which do not have sufficient amplitude.

23. An apparatus according to claim 22, wherein the third filter is constructed using a method comprising: applying a digital threshold to the product of the spectra of the two input signals.

24. An apparatus according to claim 13, wherein the at least one filter includes a fourth filter for compensating the input signals for dispersion effects.

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CORRELATION ANALYSIS IN THE PHASE DOMAIN.

This invention relates to the detection of a common signal within two (or more) input signals using correlation based techniques, and is more specifically, although not exclusively, concerned with the detection and location of leaks in water mains using correlation based techniques.

There are many applications in which signals are analysed using the technique of crosscorrelation of two data streams. This technique is specifically useful when analysing or comparing two or more composite time sequential signals within which it is believed that there is a common signal.

One area in which crosscorrelation is used is in the analysis of water leak sounds conducted along water mains, specifically locating leaks on water mains using audio sensors. The technique involves the detection and location of a common leak sound in the signals from two listening devices. It is anticipated that the sound of a leak heard remotely at one location will contain significant similarities to the sound of the same leak heard remotely at a second location. The two audio signals are therefore likely to exhibit a peak in their crosscorrelation function if there is a common source present, the position of the peak giving the time delay when the signals are similar. The peaks in the crosscorrelation function can therefore be used to deduce the location of common audio signals via the velocity of the sound in the pipe and the physical surroundings of the noise source. If the nature and persistency of the sound is indicative of leaks then there is a high probability that a leak has been found and located.

The analysis techniques described herein both for the prior art methods and the present invention are also applicable in many other technical areas. These include the following: the analysis of odd mechanical noise in equipment; the assessment of quality of objects by the noise that they make while travelling along a production line; the assessment of the performance of wheeled vehicles on road or railway tracks; the analysis of road or rail surfaces by the analysis of the sound of the passage of vehicles either on a mobile platform or at a fixed location; and the measurement of closely similar recordings (the analysis of their true relationship from a high quality digital copy to a different performance of the same song that sounds very similar).

Correlation processing techniques are frequently performed using the following process: calculate the Fourier transform of the data sets representing the two waveforms to be correlated, thereby transforming the data into the frequency domain; performing the required multiplications; and calculating the inverse Fourier transform to display the correlation function in the time domain. Often the Fast Fourier Transform is used since this allows a considerable reduction in the processing required to generate the correlation function. These techniques are well known and generally used.

The general correlation processing techniques work well, and several devices are available to perform this task. However, when the signal to noise ratio is poor and/or the bandwidth of the signals is restricted due to the propagation of the signal then the crosscorrelation function inevitably becomes degraded, with the peaks becoming less distinct or even hidden by the noise. Thus filters are used to obtain the optimum signal to noise ratio and correlation accuracy.

Noise which may be present in a signal can be considered as two distinct forms: random noise and clutter. Random noise is unpredictable on a short timescale, but has a zero mean. It may be removed by averaging over a sufficiently long period. Clutter is a function of the detected signal such as, for example, echoes and resonance, which cannot be removed by averaging.

The signal to noise ratio may be improved by filtering the input signals to reduce the bandwidth. However, as the bandwidth is reduced the width of the correlation peak tends to increase. This makes it difficult to determine the time delay when the signals are similar, and thereby makes it more difficult to determine the location of the common signal. It is therefore important to filter the signal to exclude only those bands which do not contain the useful signal. However, the prior art methods of selecting the bands are imprecise.

For example, in the case of water leak detection the audio noise signal picked up from the pipe will be a combination of the leak noise and other external or waterborne sounds. In order to improve the signal to noise ratio of the input signals the operator of a water leak detector may analyse the spectrum of the input signals to determine where signal power is significant. Filters are then set to remove the frequencies in which the signal power is not significant. This method usually provide some improvements, but does not guarantee a band with good correlation. The operator will generally need to use a combination of experience and trial and error to improve the shape of the correlation function. This process can be time consuming, often taking tens of minutes at each leak site.

The present invention seeks to mitigate these disadvantages, and to provide an improved method of detection and location of a signal using correlation based techniques.

According to a first aspect of the invention, there is provided a method for detecting and locating a common signal within two input signals using correlation based techniques, comprising providing at least one filter by analysing the phase of the input signals in the frequency domain; filtering the input signals in the frequency domain using said at least one filter; and performing crosscorrelation of the input signals.

According to a second aspect of the invention, there is provided a method for detecting and locating leaks in a fluid carrying pipe such as, for example, a water main using correlation based techniques, comprising detecting two input signals from the fluid carrying pipe; analysing the phase of the input signals in the frequency domain to provide at least one filter; filtering the input signals in the frequency domain using the at least one filter; and performing crosscorrelation of the input signals.

According to a third aspect of the invention, there is provided apparatus for detecting and locating a common signal within two input signals using correlation based techniques, comprising a computer including: means for providing at least one filter by analysing the phase of the input signals in the frequency domain; means for filtering the input signals in the frequency domain using said at least one filter; and means for performing crosscorrelation of the filtered signals.

According to a fourth aspect of the invention, there is provided apparatus for detecting and locating leaks in a fluid carrying pipe using correlation based techniques, comprising: detectors for detecting two input signals from the fluid carrying pipe; a computer including means for analysing the phase of the input signals in the frequency domain to provide at least one filter; means for filtering the input signals in the frequency domain using the at least one filter; and means for performing crosscorrelation of the filtered signals.

The signals may be audio signals.

The at least one filter may include a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence. The first filter may be constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

The at least one filter may include a second filter for identifying regions in a frequency spectrum of a cross correlation function likely to exhibit a correlated phase between adjacent frequencies in its fourier transform. The second filter may be constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the fourier transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

The time delay between the common signal in the input signals may be calculated by tracking the phase difference between the input signals as a functional frequency using the second filter. The variation in the time delay between the common signal in the input signals as a functional frequency may be calculated using a second filter.

There may be a third filter for removing frequencies which do not have sufficient amplitude. The third filter may be constructed using a method comprising applying a digital threshold to the product of the spectra of the two input signals.

The at least one filter may include a fourth filter for compensating the input signals for dispersion effects.

A specific embodiment according to the invention is provided for the detection of leaks in water mains. The apparatus may comprise a novel correlator provided on a standard field engineer's Personal Computer. The novel correlator may include a suite of signal processing algorithms and a suitable Graphical User Interface. Like current correlators the novel correlator would receive its inputs from two transducers. Input signals are processed by the computer using signal processing techniques including those described herein to detect and locate leaks.

As explained hereinbefore, the characteristics of a correlated signal are that it has similar features in its waveform (although one may be delayed with respect to each other and the whole buried in noise and interference). The crosscorrelation of two input signals will only produce a significant peak if the

frequency bands which make up those input signals have a stable phase relationship with respect to each other, i.e. the input signals have a narrow band coherence. Filtering of the two input signals to remove or suppress the frequencies which do not exhibit a sufficient degree of coherence will therefore enhance the peak in the crosscorrelation function. Frequencies which do not exhibit sufficient coherence need not be included in the final result because they will only be contributing noise. The filter profile for the signal may therefore be determined automatically.

The novel correlator includes a phase confidence filter, which is constructed to suppress the frequencies in the input signals which do not exhibit a sufficient degree of coherence. The phase confidence filter effectively indicates the estimation of how well a particular frequency will correlate, and is the result of analysing the phase stability between the input signals. One possible method for constructing the phase confidence filter would be first to calculate a phase confidence function using the following steps: to calculate the complex Fourier transform for each of a number of sections of the two input signals; to calculate the average vector sum of the phase difference between the two input signals for each frequency; and then to calculate the magnitude of the vector sum and normalise the result. Thus a function is provided which has a value of 1.0 for a given frequency which shows perfect coherence, and tends to $1/\sqrt{n}$ if the phase differences for a given frequency are random, where n is the number of samples taken. The phase confidence function may then be used as an optimal frequency weighting function to construct a filter which will include only those frequencies which contribute usefully to the crosscorrelation of the input signals.

The phase confidence filter is used in combination with an automatic band filter. The automatic band filter is constructed based purely on the amplitude of the input signals. The filter is designed to select frequencies of large amplitude, which are likely to be prominent in the crosscorrelation, and by reducing the bandwidth to hence improve the signal to noise ratio. This filter may be constructed by simply applying a digital threshold to the product of the spectra of the input signals. The threshold may be configurable by the user. The phase confidence filter and the automatic band filter are applied separately to the data.

The use of the automatic band filter addresses one practical disadvantage of the phase confidence filter. This is that some of the noise in the input signals can have highly correlated noise as a result of imperfect digitisation, this effect, seen usually at high frequencies, can produce a substantial phase confidence measurement. The automatic band filter suppresses frequencies where the signal to noise ratio is poor and this artifact is most likely to be seen.

The effect of using the phase confidence filter in combination with the automatic band filter is shown in Figs. 1 to 4. Figs. 1 and 2 show a first input signal 1 and a second input signal 2 respectively, both in the frequency domain. The crosscorrelation function 7 for the unfiltered first and second signals is shown in Fig. 3. The phase confidence filter 3 and the automatic band filter 4 are constructed for the first and second signals and applied to the signals in the frequency domain to produce a filtered first signal 5 and a filtered second signal 6. The crosscorrelation function 8 for the filtered first and second signals is shown in Fig. 4. The improvement between the crosscorrelation functions 7

and 8 can clearly be seen. There is improved clarity, with reduced background level and less ambiguous peak location.

If the common features in the input signals contain some degree of time dependency, then the phase relationship will not be stable. The use of the phase confidence filter calculated using the method above may blur the results. An alternative method for calculating the phase confidence filter would be to consider the phases for each individual section of the input signals. The process could then adapt if the phase appeared to be stable to lengthen the average by including further sections to improve the estimate.

This method could also be adapted to track the signals if they were time dependent. Consider, for example, a signal which is very noisy but has a particular value which may be either constant or changing over time. If this value is constant then it is possible to average the signal to produce the value accurately. However, if the value is changing then a compromise must be made between the number of samples over which the signal is averaged, and the rate at which the value is varying.

If to a first approximation this variation is linear it is relatively easy to produce a root mean square best straight line fit that continually updates as the data comes in. If the variation is non-linear then some means must be found of releasing the linear constraint but still producing a good curve fit. If the calculation process also produces two alternative straight line fits, one based on the first half of the data, and the other based on the second half of the data (they could be updated every other data point to ensure an even number of points) if the two lines show coherent deviation above some threshold a track deviation

can be initiated. Thereby, an adaptive signal tracking process may be developed.

The novel correlator also includes a filter based on a consideration of the phase relationships between adjacent frequencies. Relationships exist between adjacent frequencies in the different phase analyses. That is, as well as having a reasonably stable value, the phase differences may exhibit a steady progression of phase over the range of frequencies which are coherent. The source of this result can be visualised by considering a single correlation peak, a peak in the time domain is created by frequencies adding up in phase in the frequency domain. Consider firstly a centre correlation peak (often the result of an instrumental artefact or interfering signal) which is located in the centre of the correlation range and which corresponds to correlation where there is zero relative delay between two input signals. In this case the frequencies have the same or very similar phase, and therefore the phase does not change with frequency. A centre correlation peak may be removed by constructing a filter to remove frequencies having the same phase. Note, however, that exact centre correlation in the leak, although unlikely, is not impossible.

If a peak in the cross correlation function represents a delay between the input signals then frequencies in the cross correlation function of those signals are shifted in phase by an amount that is proportional to the time delay and the frequency. Frequencies evenly spaced in a Fourier Transform will exhibit a linear change of phase between adjacent correlated phases.

Considering the phases of sequential frequencies can have the advantage when the propagation bandwidth is very narrow resulting in a broad correlation peak

because the phase progression can be "unwrapped" and a straight line fitted to it.

The existence of a second major peak in the correlation result will add a second linear progression to the phase pattern. The two phase progressions will add as vectors with the result that as the relative phases of the two linear progressions move in and out of phase the main peak will be advanced and retarded in phase giving a ripple in the phase results.

Alternatively, the case where the velocity of the sound is frequency dependent may be utilised. In this case the phase progression for adjacent frequencies in a single correlation peak will not be linear. This non-linearity may be tracked. This will allow either the compensation of results for dispersion where the correlation is spread by its effects or the identification and measurement of the dispersion effects using known sound sources.

CLAIMS.

1. A method for detecting and locating a common signal within two input signals using correlation based techniques, comprising providing at least one filter by analysing the phase of the input signals in the frequency domain; filtering the input signals in the frequency domain using said at least one filter; and performing crosscorrelation of the filtered signals.

2. A method for detecting and locating leaks in a fluid carrying pipe using correlation based techniques, comprising: detecting two input signals from the fluid carrying pipe; analysing the phase of the input signals in the frequency domain to provide at least one filter; filtering the input signals in the frequency domain using the at least one filter; and performing crosscorrelation of the filtered signals.

3. A method according to claim 1 or 2, wherein the signals are audio signals.

4. A method according to any preceding claim, wherein the at least one filter includes a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence.

5. A method according to claim 4, wherein the first filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals

for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

6. A method according to any preceding claim, wherein the at least one filter includes a second filter for identifying regions in the frequency spectrum of a crosscorrelation function likely to exhibit a correlated phase between adjacent frequencies in its Fourier Transform.

7. A method according to claim 6, wherein the second filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

8. A method according to claim 6 or 7, including calculating the time delay between the common signal in the inout signals by tracking the phase difference between the input signals as a function of frequency using the second filter.

9. A method according to any of claims 6 to 8, including calculating variations in the time delay between the common signal in the input signals as a function of frequency using the second filter.

10. A method according to any preceding claim, including using a third filter to remove frequencies which do not have sufficient amplitude.

11. A method according to claim 10, wherein the third filter is constructed using a method comprising: applying a digital threshold to the product of the spectra of the two input signals.

12. A method according to any preceding claim, wherein the at least one filter includes a fourth filter for compensating the input signals for dispersion effects.

13. Apparatus for detecting and locating a common signal within two input signals using correlation based techniques, comprising a computer including: means for providing at least one filter by analysing the phase of the input signals in the frequency domain; means for filtering the input signals in the frequency domain using said at least one filter; and means for performing crosscorrelation of the filtered signals.

14. Apparatus for detecting and locating leaks in a fluid carrying pipe using correlation based techniques, comprising: detectors for detecting two input signals from the fluid carrying pipe; a computer including means for analysing the phase of the input signals in the frequency domain to provide at least one filter; means for filtering the input signals in the frequency domain using the at least one filter; and means for performing crosscorrelation of the filtered signals.

15. Apparatus according to claim 13 or 14, wherein the signals are audio signals.

16. Apparatus according to any of claims 13 to 15, wherein the at least one filter includes a first filter for suppressing frequencies which do not exhibit a sufficient degree of coherence.

17. Apparatus according to claim 16, wherein the first filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

18. An apparatus according to any of claims 13 to 17, wherein the at least one filter includes a second filter for identifying regions in the frequency spectrum of a crosscorrelation function likely to exhibit a correlated phase between adjacent frequencies in its Fourier Transform.

19. An apparatus according to claim 18, wherein the second filter is constructed using a method comprising: selecting at least one section from each of the two input signals; calculating the Fourier Transform for each section; calculating the average vector sum of the phase difference between the two input signals for each of a plurality of frequencies; and calculating the magnitude of the vector sum for each frequency.

20. An apparatus according to claim 18 or 19, including calculating the time delay between the common signal in the inout signals by tracking the phase difference between the input signals as a function of frequency using the second filter.

21. An apparatus according to any of claims 18 to 20, including calculating variations in the time delay between the common signal in the input signals as a function of frequency using the second filter.

22. Apparatus according to any of claims 13 to 21, including a third filter to remove frequencies which do not have sufficient amplitude.

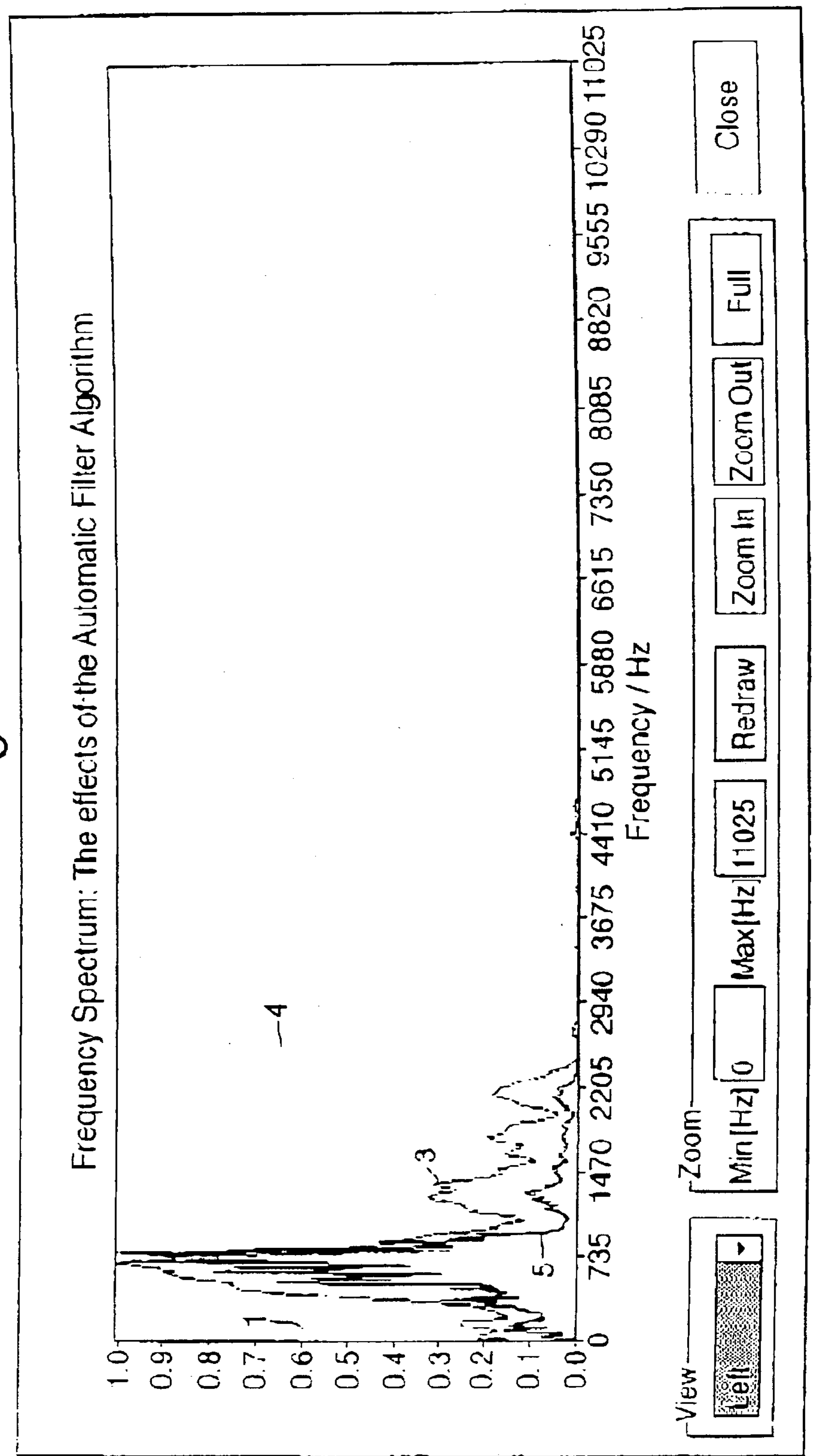
23. Apparatus according to claim 22, wherein the third filter is constructed using a method comprising: applying a digital threshold to the product of the spectra of the two input signals.

24. Apparatus according to any of claims 13 to 23, wherein the at least one filter includes a fourth filter for compensating the input signals for dispersion effects.

ABSTRACT

Method and apparatus for detecting and locating leaks in a fluid carrying pipe using correlation based techniques is described. Two input signals are detected from the fluid carrying pipe, the phase of the in put signals in the frequency domain is analyzed o provide at least one filter, the input signals are filtered and cross-correlation is performed on the filtered signals.

Fig.1.


Frequency Spectrum: The effects of the Automatic Filter Algorithm
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 735 1470 2205 2940 3675 4410 5145 5880 6615 7350 8085 8820 9555 10290 11025
Frequency / Hz
1
3
4
5
View
Left
Zoom
Min [Hz] 0
Max [Hz] 11025
Redraw
Zoom In
Zoom Out
Full
Close

10/019180

Fig.2.

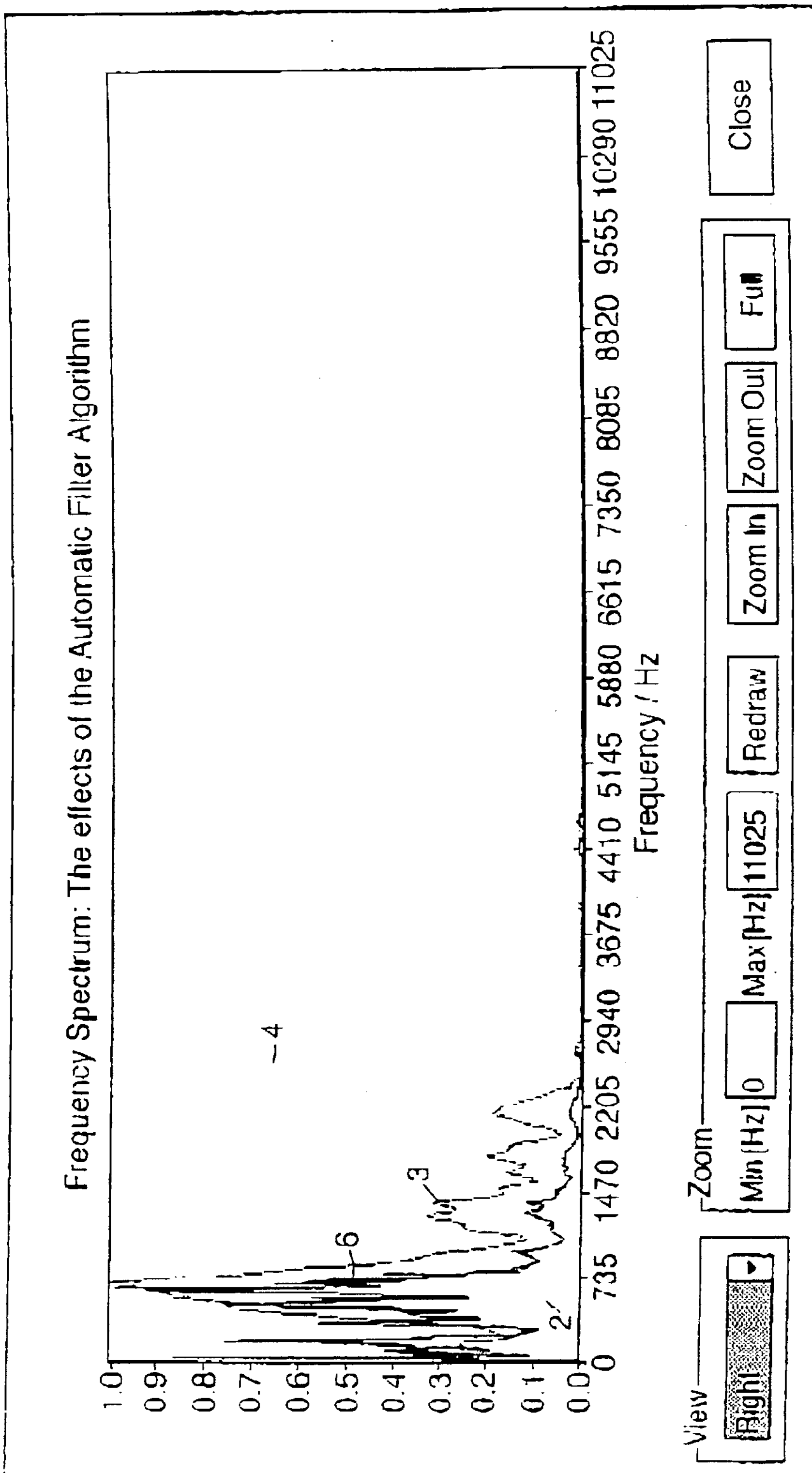


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Fig.3.

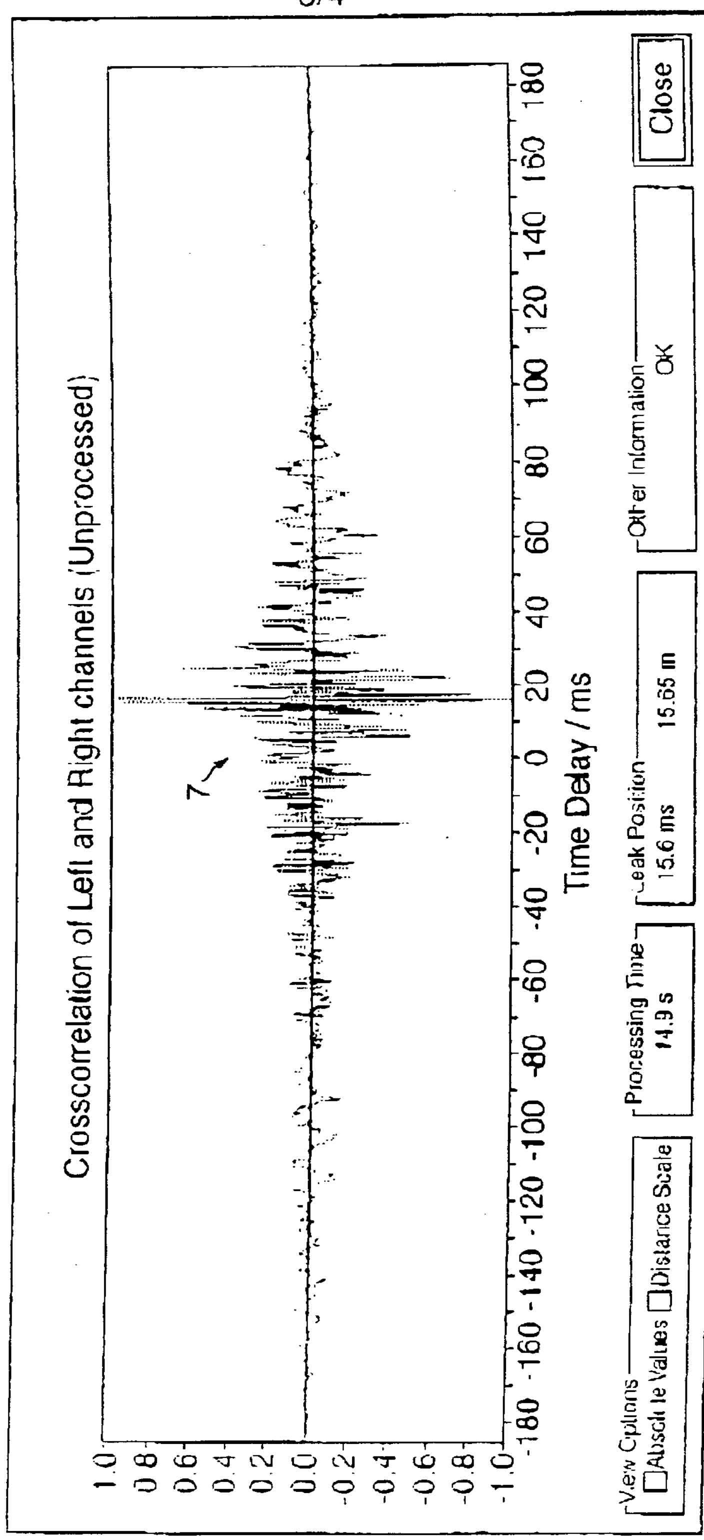
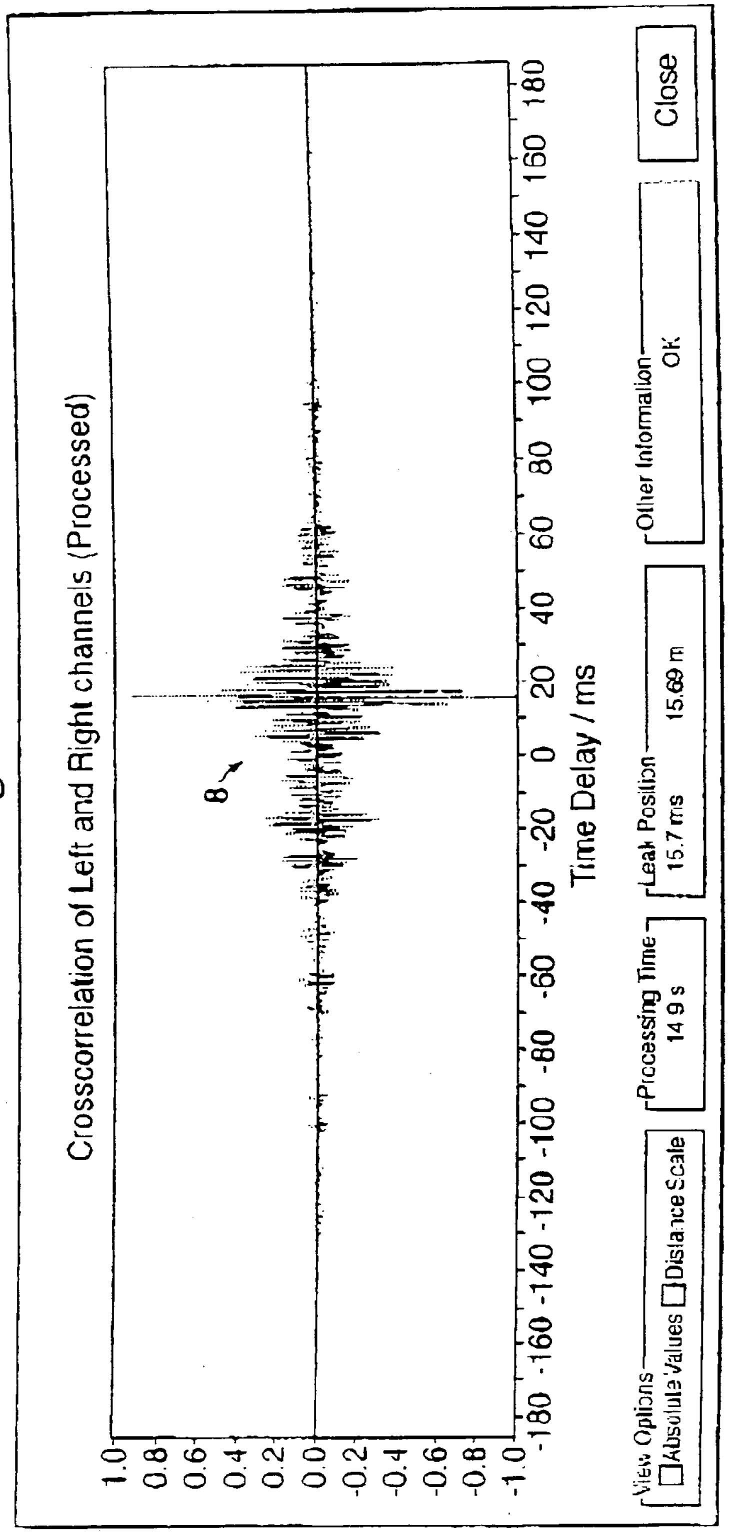


Fig.4.


Crosscorrelation of Left and Right channels (Processed)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180
Time Delay / ms
8
View Options
Absolute Values
Distance Scale
Processing Time
14 9 s
Leak Position
15.7 ms
15.69 m
Other Information
OK
Close

ATTY. DOCKET NO.: EEC-TWUL-P2

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose material information as defined Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.) (Filing Date) (Status)(patented, pending, abandoned)

(Application Serial No.) (Filing Date) (Status) (patented, pending, abandoned)

As a named inventor, I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: Glenn F. Ostrager, Reg. No. 29,963; Leighton K. Chong, Reg. No. 27,621; Dennis M. Flaherty, Reg. No. 31,159; Joshua S. Broitman, Reg. No. 38,006; Manette Dennis, Reg. No. 30,623, Donald A. Baricevac, Reg. No. 44,021, and Eric Lerner, Reg. No. 46,054.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

ATTY. DOCKET NO.: EEC-IWUL-P2

Declaration For Patent Application and Power of Attorney

As the below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **CORRELATION ANALYSIS IN THE PHASE DOMAIN**, the specification of which

(check one)

[] is attached hereto.

[X] was filed on June 22, 2000 as Application Serial No. PCT/GB00/02434 and was amended on ______ (if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

(Number)	(Country)	(Day/Month/Year Filed)	Priority Claimed	
9914567.4	Great Britain	22 June 1999	[x] Yes	[] No
			[] Yes	[] No

ATTY. DOCKET NO.: EEC-TWIIL-P2

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Full name of third inventor:

Inventor's signature Date

Residence:

Citizenship:

Post Office Address: same as above

Signed and declared by the above named IAN D KIMBER and ROBERT ALCOCK in my presence having identified themselves to me at Uxbridge England this 13th June 2002

MARTIN D. SILVERMAN
NOTARY
PUBLIC
UXBRIDGE, ENGLAND